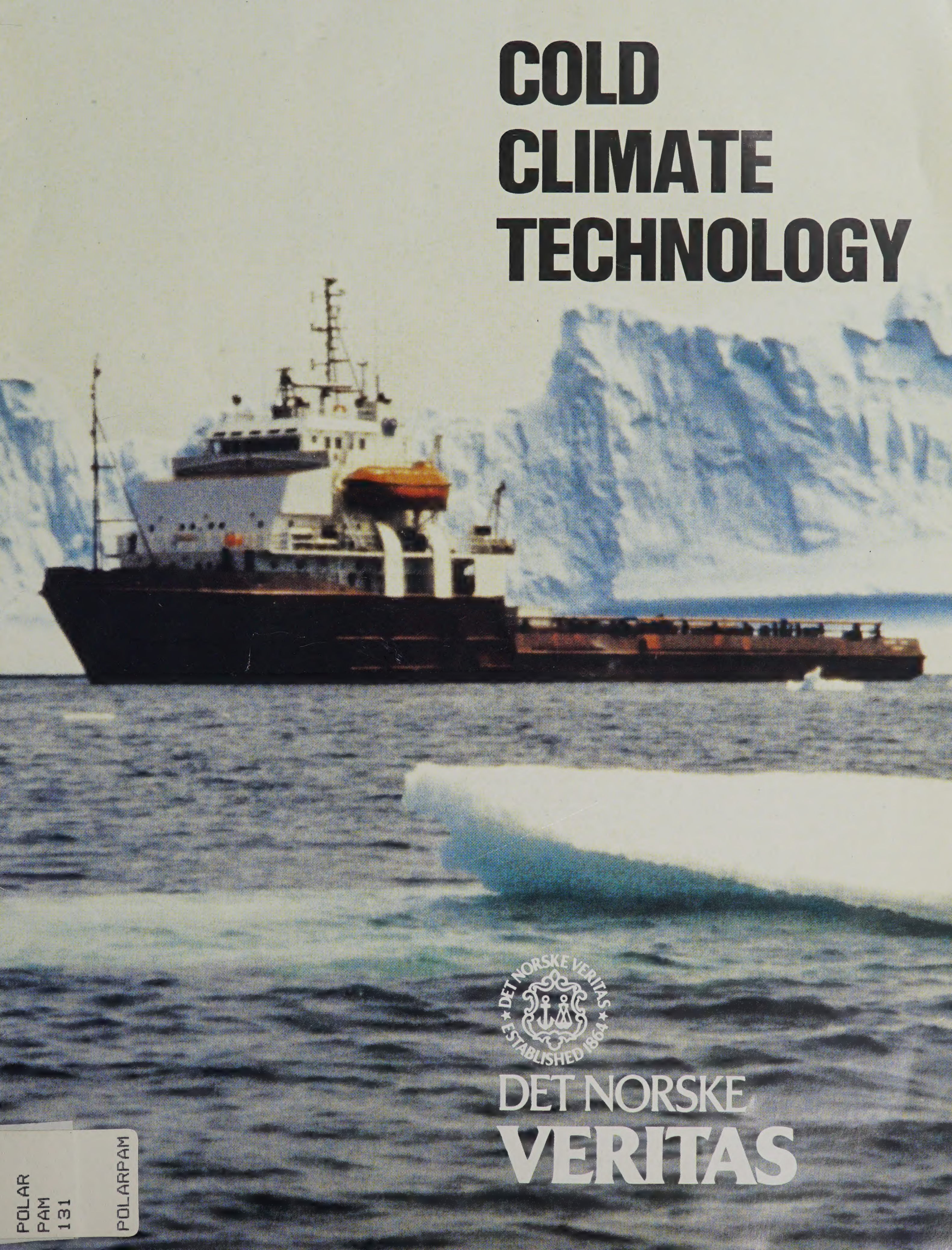
COLD CLIMATE TECHNOLOGY



DET NORSKE
VERITAS

POLAR
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POLARPAM

EARLY INVOLVEMENT IN ARCTIC NAVIGATION

Norwegian explorers have played a paramount role in the discovery and development of cold regions since the Viking voyagers. Roald Amundsen was the first to set foot on the South Pole with his party on 14 December, 1911. He also successfully navigated the Northwest Passage and opened up new areas in the US and Canadian Arctic. Fridtjof Nansen led three major expeditions to Arctic regions in 1893—1902 together with Sverdrup, Heiberg, the Ringnes brothers and others. He also crossed Greenland on skis in 1888. Norwegian sealers, and later whalers, have also traded actively in polar waters since the beginning of 1800.

The development of means of transportation to support these exploratory activities was by itself a major undertaking. It took the best of naval architects, shipbuilders and outfitters to come up with vessels and equipment that would endure the new and little known hostile environments.

Amundsen and his party at the South Pole in December 1911.

Det norske Veritas, a ship classification society established in 1864, has also contributed to the successful implementation of these bold marine ventures. Nansen's vessel «Fram», which he and Amundsen used frequently for the Arctic expeditions, was designed and built by Colin Archer with whom VERITAS had a close relation.

Amundsen's vessel, «Gjøa», built in western Norway and used for the Northwest Passage (1903—06) was classed with VERITAS.

DEVELOPMENT OF RULES FOR SHIPS IN ICE

The first VERITAS rules on ice-strengthening of ships were issued more than one hundred years ago. In the first «Rules for the Construction of Steel Ships», published in 1872, it is stated that:

«In all vessels for navigation in ice, the frames in the foremost part of the forebody are to be placed closer together than here stipulated, or other necessary internal stiffening has to be provided in a satisfactory manner.» and

«On all vessels for navigation in ice, two strakes at the waterline in the foremost part of the ship's forebody are given a somewhat greater thickness than stipulated.»

The first Finnish governmental statutes concerning outfitting of ships for winter navigation in the Baltic were passed in March 1890. During subsequent years, the further development of Baltic ice rules have set standards for ships in ice. In 1960, VERITAS introduced three ice-classes complying with Baltic regulations, and have actively participated in further development work.

Today VERITAS is proposing extended ice-classes, based on state-of-the-art expertise in ship/ice interaction and safe Arctic navigation.

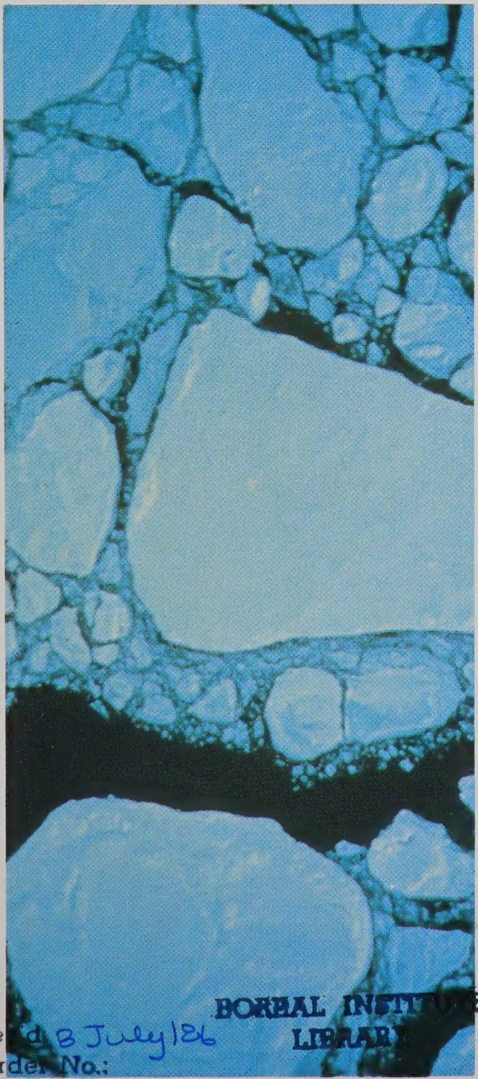
Det norske Veritas issued the class certificate on GJØA.

VERITAS AND COLD CLIMATE TECHNOLOGY

Det norske Veritas is an international organization, working for safety on land and at sea. As a result of VERITAS' world-wide activity as a ship classification society and verification authority on offshore installations, competence within cold climate technology (CCT) is a prerequisite for related work in frontier areas. VERITAS is therefore investing considerable funds and resources to expand their expertise within CCT.

The major activities relate to:

- Classification and certification/verification according to existing rules.
- Development of new rules for ships and offshore structures in ice.
- Research and development.
- Advisory services.



Canadian experimental bulk carrier M/V ARCTIC.

Ice technology is one area that has been given high priority within VERITAS. In 1981 a centre for VERITAS' CCT research and development was established in Calgary, Canada, which co-ordinates the society's efforts in this sector. Principal activities are within the following areas:

- Environmental conditions, ice mechanics and loads.
- Ice/structure and ice/ship interaction.
- Material technology.
- Risk and reliability.

NAVIGATION IN ARCTIC WATERS REQUIRES SPECIAL ICE CLASSES

As industrial activities move into colder areas, there is an increasing need for ships designed and strengthened to deal with the more severe ice conditions and lower temperatures encountered. Extensive hull damages are likely to occur when a ship is operated in ice conditions more severe than those for which it has been designed. Propellers and rudders are also particularly vulnerable.

To assure the safety and efficiency of ships operating in such waters, VERITAS has established special rules for strengthening of ships navigating in ice.

BASIC ICE CLASSES AND RELATED ICE CONDITIONS

The rules apply specifically to five general ice classes enabling vessels to navigate in ice infested sub-Arctic areas during the winter season and Arctic and Antarctic areas during the summer season.

The notations are ICE-1A*, -1A, -1B, -1C and -C, representing design criteria derived from first year ice up to one metre in thickness. Icebreaker assistance is, however, assumed in the most severe conditions for each class notation.

These class notations are recognized by Swedish-Finnish authorities for winter navigation in the northern Baltic and by Canadian authorities for summer navigation in Canadian Arctic waters.

SPECIAL ICE CLASSES AND RELATED ICE CONDITIONS

Unassisted winter navigation in Arctic or Antarctic areas requires special consideration of icebreaking capabilities and strength. Vessels intended for such navigation have, up to the present, been classified based on in-house standards, on a case-to-case basis with no specific

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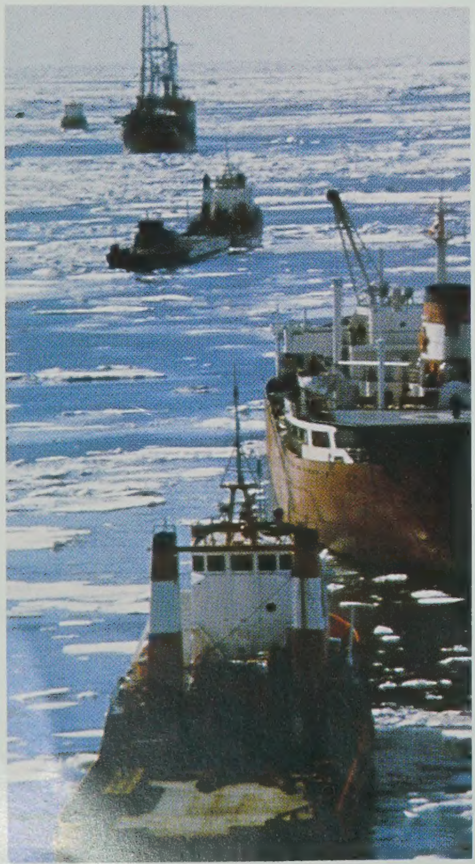
class notation offered except for the notations **Icebreaker** and **Arctic Icebreaker**. Based on the experience gained over many years of classifying vessels for navigation in the harsh environment of Arctic areas of northern Europe, Canada and USA, VERITAS has prepared general rules for class notations suitable for vessels regularly navigating in these areas. The design conditions cover operation in ice ranging from 0.5 metres up to 3 metres in thickness and include, where appropriate, consideration of impacts with ridges and bergy bits as well as selection of steels for low temperature applications. The new class notations, initially proposed in their basic form, are designed to meet relevant levels of the Canadian Arctic Shipping Pollution Prevention Regulations.

The VERITAS Arctic Class concept in its fully developed form will set standards believed to meet the development trends of regulatory requirements, and will be a useful general tool for designers of ships intended for navigation in the cold and ice covered waters of the Arctic and Antarctic regions.



Arctic navigation in the Canadian North.

OPERATIONS OF SHIPS IN ICE

VERITAS has carried out a research project «Operations of Ships in Ice» in close cooperation with Scandinavian shipowners.

The objectives of the project were to:

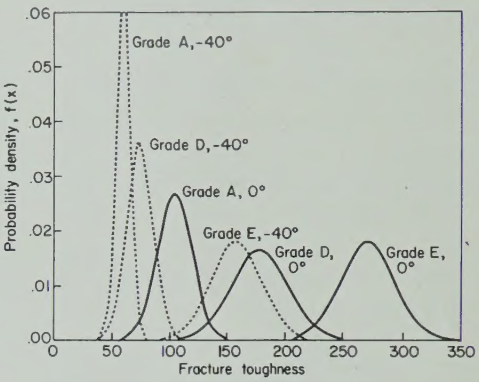
- Increase the general knowledge of how to operate ships in ice,
- Determine the appropriate ice-strengthening from an operational viewpoint, and
- Evaluate the cost effectiveness of winter navigation.

VERITAS' CCT Centre in Calgary has initiated a second internal project with an extended scope of work. The study's objectives are:

- Compilation and analysis of ice damage incidents specific to Canadian waters (e.g. Arctic, St. Lawrence),
- Development of an ice transiting simulation model incorporating techniques for analysing ice detection and avoidance, and which results in a probability of damage given a route and time of transit, and
- Revision of current ice/structure interaction models.

ARCTIC MATERIAL STANDARDS

Design and construction requirements for ships, offshore structures and pipelines are frequently extended to cover new and complex situations, including harsh Arctic environments. The capacity of steels is therefore utilized to a higher degree, making the structures less tolerant to design and construction weaknesses and more sensitive to deterioration by fatigue and corrosion. Proper selection of materials, application of controlled fabrication conditions and corrosion control programs are essential to assure structural integrity and acceptable operational safety. Criteria for Arctic material selection need to reflect the possibility of different modes of failure such as extensive yielding, buckling, fatigue fracture and brittle fracture and also resulting consequences to the structural integrity. VERITAS has developed the computer program PROBAN for probabilistic failure analysis, and this program has been used successfully to make recommendations for the changes in plating of the M/V «Arctic». VERITAS has also provided significant input to the discussions on Canadian structural steel standards for Arctic Class ships. Basic development work has also been offered on steel plate requirements for fixed offshore structures, as contributions to new Canadian offshore standards that will also address frontier developments.

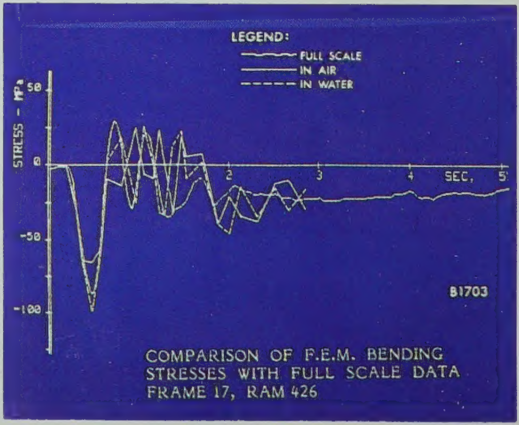


Fracture toughness distributions.

NEW APPROACHES SHIP/ICE INTERACTION

The VERITAS CCT group has carried out an extensive FEM assignment for CANMAR/Canadian Coast Guard on the icebreaker M/V «Kigoriak» in ramming multi-year floes.

A study has also been carried out on iceberg/bergy bit collision damage on an Arctic LNG tanker for a major oil company. Fundamental research is being conducted on the development of collision damage models and consequence analysis for mobile offshore units operating in ice.

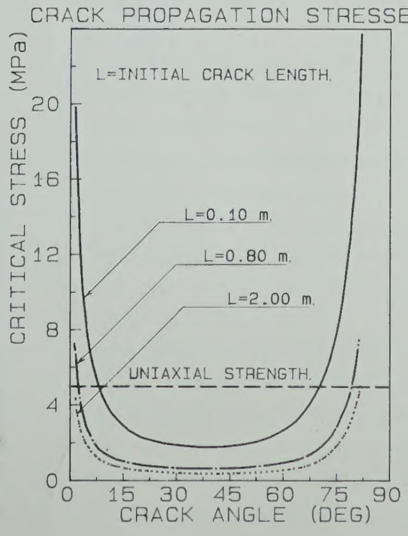


CANMAR'S drilling structure SSDC on location in Beaufort Sea. SSDC is classed with VERITAS.

ICE/STRUCTURE INTERACTION

The choice of appropriate design criteria for ice loading on Arctic offshore structures is dependent on the capability to arrive at realistic estimates of the local pressures and the global forces resulting from ice/structure interaction. This is a highly challenging task involving numerous sources of variability. Several types of ice/structure interaction scenarios may occur, including open water collisions with icebergs or ice floes, movement of full first year ice covers against a structure, and the possibility of interaction with extreme features such as pressure ridges. These ice features form and deform under variable natural forces and conditions and are, therefore, highly irregular. In addition, ice is extremely brittle and exists in nature at high homologous temperatures. These factors result in complexities in its mechanical behaviour under loading.

VERITAS has carried out a state-of-the-art review of the available methods for estimating ice forces. Early approaches concentrated on conservative idealizations of the geometry and mechanical properties of the ice in a manner which allows the use of the existing theories which are developed for engineered materials. Recognizing the need to advance the present approaches toward a more accurate representation of the reality of ice/structure interaction, VERITAS has channelled research effort in this direction. This includes finite element analysis of ice sheet indentation, using realistic constitutive models for the ice and taking into account the dependence of the behaviour of ice on the deformation rate. Since cracks and fissures exist in natural ice, investigations of the failure loads of cracked specimens and ice floes have been undertaken using fracture mechanics. The statistical aspects relating to the uncertainties associated with the frequencies and severities of ice loading scenarios are also essential for the choice of design criteria, and VERITAS has utilized the probabilistic approach to arrive at rational design criteria for structures and vessels in ice.



Stresses initiating crack propagation in ice.

RISK AND RELIABILITY

The general question of how much safety to incorporate in a system is at the root of VERITAS' involvement in offshore engineering. Absolute safety is not a realistic objective since there is no human activity that does not include some risk. In addition, projects have to be carried out with reasonable economy. These factors suggest an approach based on risk analysis. The principal aspects to be studied in the Arctic environment are:

- Structural safety.
- Safety with respect to human life and possible injury.
- Safety with respect to accidents.
- Safety of the environment, avoidance of pollution and related matters.
- Risk avoidance and reduction, evacuation, safe procedures and equipment.
- Other risks, including financial risks and production downtime.

These risks are not much different from those encountered elsewhere in offshore development, but the Arctic poses special problems such as those associated with:

- The presence of ice and consequent loads on structures and ships.
- Extremely hostile environment.
- Cold temperatures and the effect both on safety, human response and materials (brittle fracture).
- Long hours of darkness in winter and its effect on safety.

The analysis of the factors noted above can be structured as follows:

- Problem idealization, identification of causes and consequences.

CANMAR's icebreaker KIGORIAK on ramming tests in Canadian Beaufort.

- Probability of causes.
- Quantification of consequences.
- Risk analysis and risk reduction.

VERITAS has a large variety of procedures and computer programs to carry out required analyses. These might relate to probabilistic analysis of the Arctic environment, evaluation of the extent of an oil spill, consequences of a fire or explosion or the probability of encounter with an iceberg. An evaluation of the most cost-effective means for reducing risk can also be provided with such analyses, if desired.

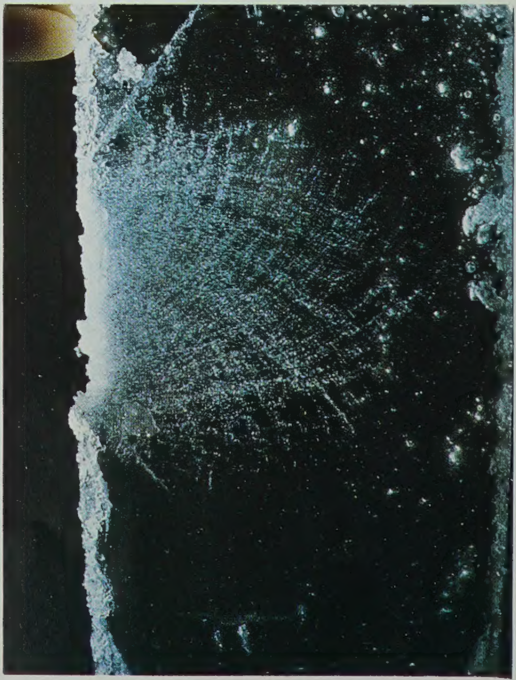
VERITAS' CCT PROJECTS AND PROGRAMS

Since 1981, VERITAS' Calgary office has carried out a number of internally and externally funded R&D projects related to CCT.

Some recent CCT projects carried out for external clients include the following:

- Evaluation of cold temperature brittle fracture properties of various steel grades for Arctic ships.
- Arctic tanker and iceberg/tanker collision studies.
- Review and recommendations on steel grades for Arctic class ships.
- Study of load-line stability criteria for Arctic navigation.
- Structural review and FEM analyses for Arctic concrete drilling caison.
- State-of-art description of methods for computation of global and local loads in ice/structure interaction.
- Three-dimensional FEM of icebreaker subject to ice-ramming loads.

Development of fracture zones in indentation tests carried out by VERITAS and NRC.



- Study on probability based design criteria for ice loads on fixed structures in the Beaufort Sea.
- Analytical models related to experimental work on ice/structure interaction.
- Study of added mass concept in FEM work related to icebreaker.
- Risk assessments of floating production systems subject to ice loading.
- Development of steel plate requirements for fixed offshore structures.
- Analyses of the geometry of multi-year ridges based on existing field measurements.
- Beaufort Sea extreme wave studies assessment.
- Probabilistic assessment of ice loading on monopod jack-up structure.

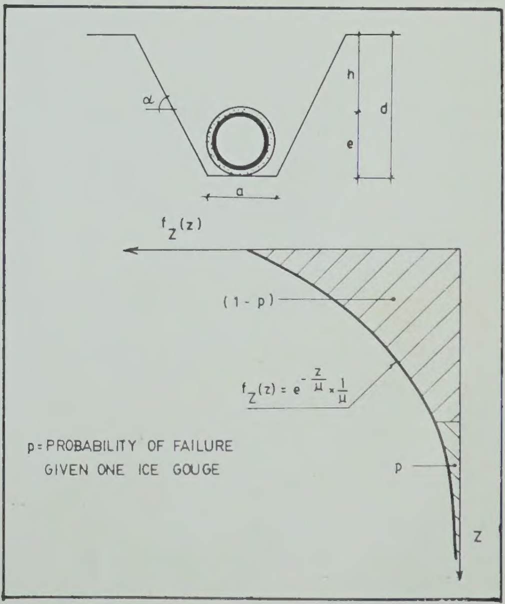
EXTERNAL CLIENTS INCLUDE

ARCO International
BP/Sohio
COGLA
CANMET
Canterra Energy
Canadian Coast Guard
Canada Dept. of Public Works.
Dome Petroleum/CANMAR
EPOA (CPA)
Elf Aquitaine
Exxon Production and Research
Geological Survey of Canada
Global Marine Development
Gulf Canada Resources
I.H.I. Ltd.
Kajima Corp.
Melville Shipping
Mobil (MRDC)
Norwegian Contractors
Petro-Canada
Taisei Corp.
Tecnomare
Transport Canada, TDC
Union Oil

Several internal CCT programs have been carried out to enhance VERITAS' ice technology. This work includes the development of rules for Arctic structures and vessels, statistical analysis of the Arctic environment (e.g. ice, permafrost, icing) and the development of the technology required for safe and economic engineering in cold regions. Key reports are covering following topics:

The harsh-weather rig POLAR PIONEER, classed with VERITAS. Structural components have design temperature of -20°C.

- Loading on vertical structure by multi-year ridges.
- Models for simulation of ridge impacts on fixed structures.
- Probabilistic analysis of ice impacts.
- Multi-year ice floe morphology.
- Risk assessment of ice loading for fixed structures.
- Icing and associated problems.
- Frozen soil engineering.
- Protection of Arctic offshore pipelines against scour.
- Review of the use of steel and welding in the Arctic.
- Statistical methods for loads from multi-year floes in the Beaufort Sea.
- FEM of some ice/structure interaction problems, using fracture mechanics, damage mechanics and non-linear creep laws.
- Probabilistic evaluation of design criteria for Arctic shipping.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$f_z(z)$
(1 - p)
$f_z(z) = e^{-\frac{z}{\mu}} \times \frac{1}{\mu}$
p = PROBABILITY OF FAILURE GIVEN ONE ICE GOUGE
p
z

Risk study of gouging of pipelines by ice features.

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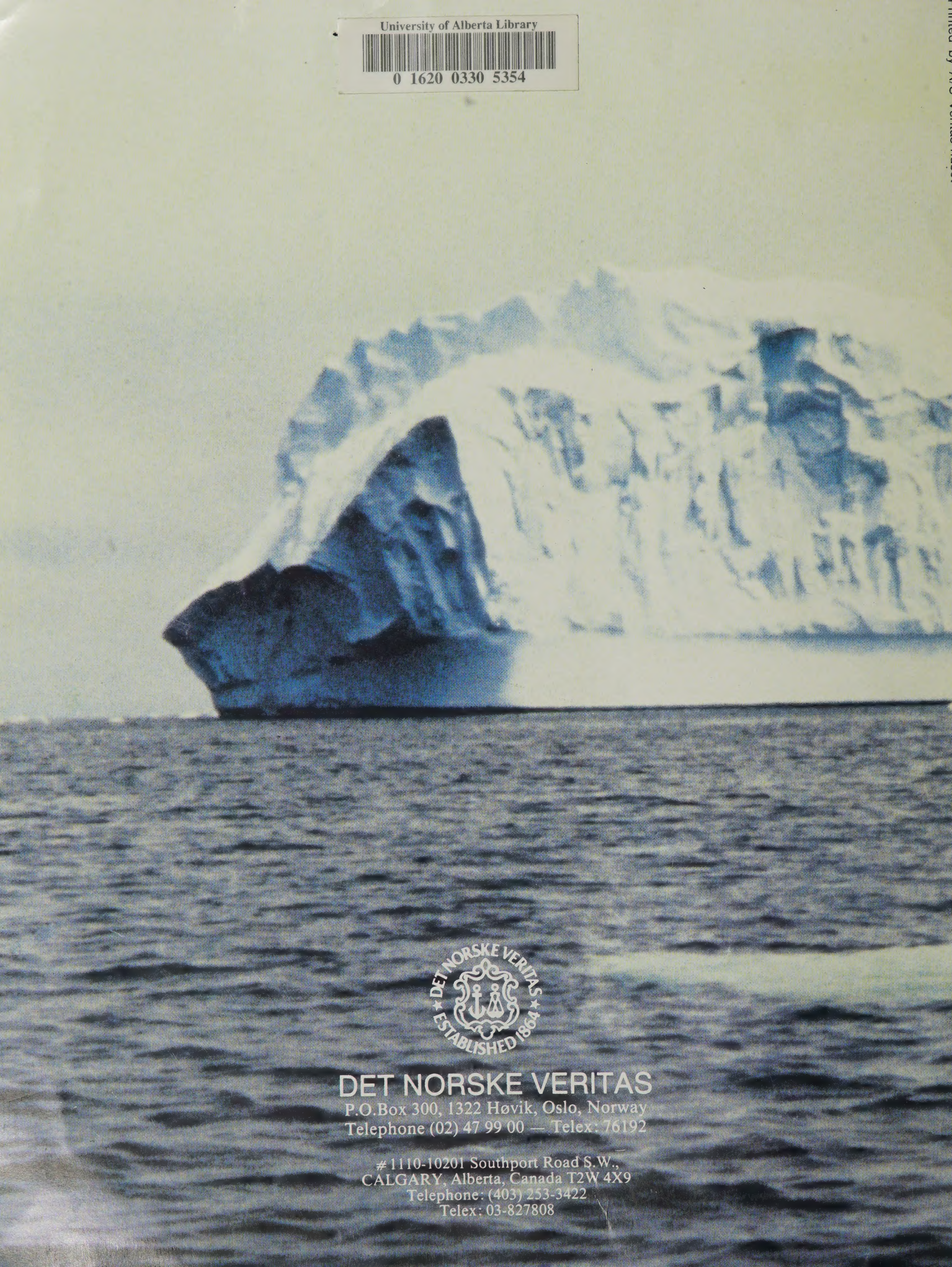

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